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Articles

Water quality of the wellsprings from the natural wetland "Cienega de Tamasopo" in San Luis Potosí, Mexico

Calidad del agua de los manantiales del humedal natural "Ciénega de Tamasopo" en San Luis Potosí, México

Cynthia Wong-Arguelles[1], ORCID: https://orcid.org/0000-0001-9637-5023

Angel J. Alonso-Castro[2], ORCID: https://orcid.org/0000-0003-2660-8156

Candy Carranza-Álvarez[3], ORCID: https://orcid.org/0000-0002-6456-3035

[1]Programas Multidisciplinarios de Posgrado en Ciencias Ambientales, Universidad Autónoma de San Luis Potosí, San Luis Potosí, San Luis Potosí, México, cwongar13@gmail.com

[2]Departamento de Farmacia, División de Ciencias Naturales y Exactas, Universidad de Guanajuato, Guanajuato, México, angeljosabad@hotmail.com

[3]Unidad Académica Multidisciplinaria Zona Huasteca, Universidad Autónoma de San Luis Potosí, Ciudad Valles, San Luis Potosí, México, candy.carranza@uaslp.mx

Correspondence author: Candy Carranza-Álvarez, candy.carranza@uaslp.mx

Abstract

The aim of this work was to evaluate the quality of eleven available springs from the natural wetland "Ciénega de Tamasopo", which are the main available water sources for human use among the population of this ecosystem. Currently, there is insufficient information about the physicochemical and biological parameters of these springs. The microbiological analysis and in situ parameters, such as temperature, pH, total dissolved solids, and turbidity were measured in the 11 springs within two sampling seasons. The results were compared with national (Ecological Criteria for Water Quality, 1989, Official Mexican Standard Modified NOM-127-SSA1-1994) and international legislations (Environmental Protection Agency (EPA) and World Health Organization (WHO), to determine whether the quality of spring water is adequate for human consumption. The problems faced by these springs are varied due to anthropogenic and agricultural activities. Therefore, it is necessary to undertake new projects and activities to secure their protection and good use, and thus, avoid their deterioration.

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Keywords: Water quality, natural wetlands, springs.

Resumen

El objetivo de este trabajo fue evaluar la calidad del agua de 11 manantiales del humedal natural “Ciénega Tamasopo”, los cuales son la principal fuente de agua disponible para uso humano entre la población alrededor de este humedal. Actualmente no existe información suficiente de los parámetros fisicoquímicos y biológicos de tales manantiales. El análisis microbiológico y los parámetros *in situ* como temperatura, pH, sólidos totales disueltos y turbidez se midieron en los 11 manantiales en dos temporadas de muestreo. Los resultados obtenidos se compararon con las legislaciones nacionales (Criterios Ecológicos de Calidad del Agua, 1989, Norma Oficial Mexicana Modificada NOM-127-SSA1-1994) e internacionales (Agencia de Protección Ambiental y Organización Mundial de la Salud) para determinar si la calidad del agua de los manantiales es adecuada para el consumo humano. La problemática que enfrentan los manantiales es variada debido a las actividades antrópicas y de agricultura. Por ello es necesario emprender actividades y proyectos para su protección y un buen aprovechamiento, a fin de evitar su deterioro.

Palabras clave: calidad de agua, humedal natural, manantiales.

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Introduction

Wetlands are one of the most important ecosystems on Earth. They play a key role in preventing floods and purifying and filtering out pollutants or excess nutrients from water (Guo, Li, Sheng, Xu, & Wu, 2017) since they act as sedimentation traps or as chemical detoxifying agents (Suhani, Monika, Vaish, Singh, & Singh, 2020). In addition, wetlands favor the recharge of water bodies and surface-water systems (Conanp, 2020; Ramsar, 2020). Furthermore, water is the main factor that determines which type of plants and animals will inhabit these aquatic systems (Moreno-Casasola, 2016). In some rural areas, wetlands represent a source of water supply, health and the water quality are directly related to the way of life and the economic activities of the inhabitants (Musalem, Jiménez, & McDonald, 2014; Kaur, Walia, Mabwoga, & Arora, 2017).

Mexico has 142 wetlands of international importance and ranks second worldwide due to the presence of these ecosystems (Conanp, 2020). The state of San Luis Potosí, Mexico has a natural freshwater wetland called Ciénega de Tamasopo, located in the Pánuco Hydrological Region (RH-26) in the Bajo Pánuco subregion (Carbajal *et al*., 2015), which is part of the Micro basin No. 40 (also known as "Ciénega de

Tamasopo") , and has an area of 26,452.96 ha. It is one of the last lentic wetlands with a neotropical climate in the state of San Luis Potosí, and its protection and conservation are a priority. The water inputs of this wetland come from rainwater and springs located in the upper part of the basin (Pérez-Castillo, Alfaro-De-la-Torre, Pérez-Rodríguez, & Comín Sebastián, 2017). Moreover, springs are of great importance since they permanently feed the wetland´s water column. Springs are surface outcrops of groundwater, and when there is high-quality water, these can be used as a source of water for human consumption. However, the water quality of these springs depends on the geological conditions of the environment where they circulate. In this context, before water emerges to the earth's surface, it can be enriched with minerals and it can also be contaminated by the influence of anthropogenic activities (Derso, Beyene, & Getachew, 2015; Silva-García, Ochoa-Estrada, Cruz-Cárdenas, Nava-Velázquez, & Villalpando-Barragán, 2016). For this reason, it is important to assess the water quality of the springs that supply water to wetlands, given that these ecosystems are currently experiencing a decrease in their water quality due to low levels of sedimentation, presence of salts, and high concentration of nutrients (Kulinkina *et al*., 2016; Lintern *et al*., 2018).

Given the importance of these water bodies, the objective of this study was to evaluate the water quality of the 11 springs that supply the Ciénega de Tamasopo wetland. Several physicochemical parameters (temperature, total dissolved solids, electrical conductivity, turbidity, total hardness, calcium hardness, and SO_4^{-2} and NO_3^- anions), including microbiological parameters, were determined twice within one year (July and October 2017).

Materials and methods

Study site

The Ciénega de Tamasopo wetland is a freshwater swamp located in the Neotropics in central Mexico (Ramsar, 2008). It is a rainwater collector (surface water) and a groundwater discharge zone. There is the main current that flows from the upper part (north) that collects water from the secondary currents forming the "El Trigo" or "Cabezas" stream, which has a Declaration of National Property (No. 137), as well as other springs of permanent character and spontaneous outcrop, including "El Trigo" or "Cabezas", "Ojo de Agua Grande", "Ojo de agua del Zopilote", "Ojo de Agua de Cofradía", "Ojo de Agua de la Presa Mocha "," Ojo de Agua de San Javier "," Ojo de Agua del Lagarto "," Ojo de Agua de Juan Shilote ", and" Ojo de Agua de Capuchinas ". El Trigo or Cabezas spring, considered as the origin of the “El Trigo” stream, is the main current within the Ciénega (approx. 20 km long) and is partly well defined, but there are long stretches where the water disappears (Ramsar, 2008; Pérez-Castillo, Alfaro-De-la-Torre, Briones-Gallardo, & Medellín-Milán, 2015).

The average rainfall is 1 500 mm with intensive rainfall from July to September. The precipitation causes a significant increase in the level of the water column, which causes floods in the sugar cane fields and some cattle lands. During the field visits, it was found that nearby houses do not have drainage systems and use latrines (wet or dry).

Agriculture and livestock can be found in the micro-basin. Cultivation of sugar cane is the main agricultural activity, whereas the extensive and semi-intensive rearing and fattening of cattle are the main livestock activity. Agricultural activities, such as the expansion of the surface area, the production of sugar cane, the use of chemical fertilizers and pesticides, as well as the exploitation of water resources and soil have an ecological impact due to the environmental pressure exerted by this environmental damage (Pérez-Castillo *et al*., 2017).

Figure 1 shows the eleven springs surrounding the Ciénaga de Tamasopo wetland: “Cabezas” (M1), “Escuranas 1” (M2), “Escuranas 2” (M3), “El Cuajo” (M4), “San Isidro” (M5), “Cofradías” (M6), “Presa Mocha” (M7), “Agua de las Piedras” (M8), Plan de Juanchilote” (M9), “Capuchinas” (M10), and “El 20”(M11).

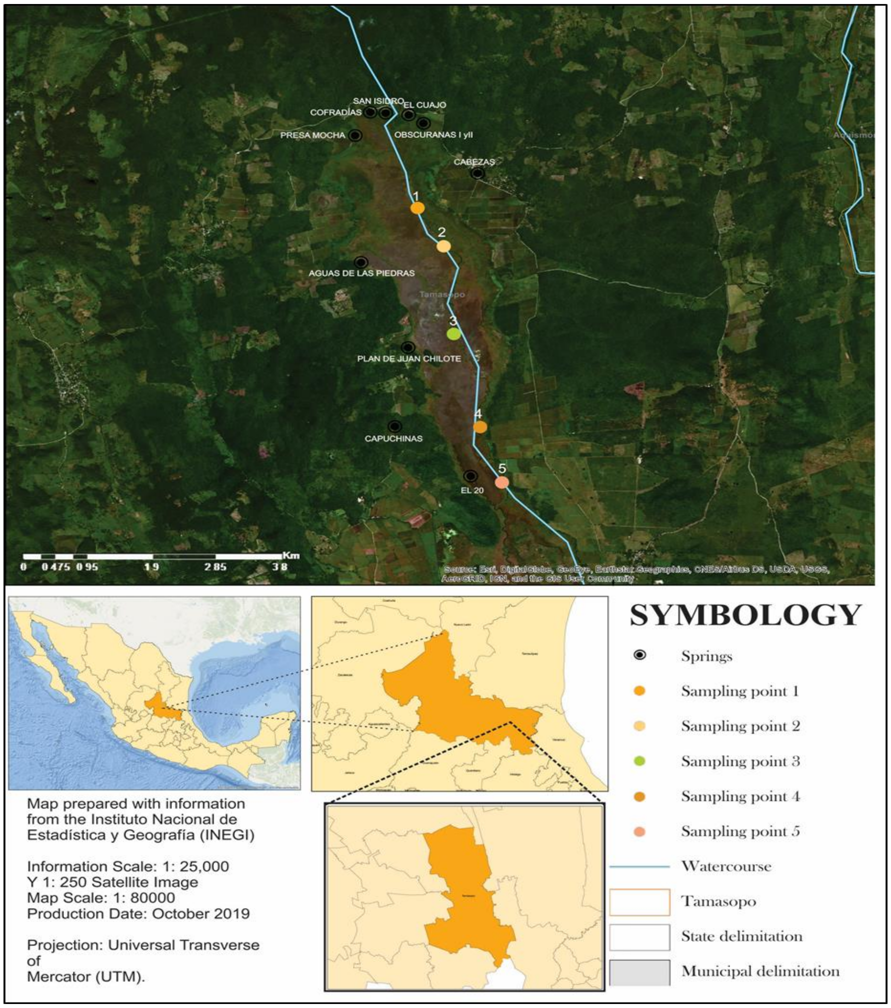

Figure 1. Localization of the springs surrounding the natural wetland Cinénega de Tamasopo, México. Elaboration considering: INEGI (2010).

Water sampling analysis

Water samples were collected from the springs (M1-M11) surrounding the Ciénega de Cabezas natural wetland during two sampling stages (July and October 2017). The depth of the springs varied between 0.5 and 1.3 m, presenting a rocky bed. During the water sampling process, the presence of plants, some electric water pumps, fauna (pigs, cattle, and birds), and empty fertilizer containers, was observed. The access for water sampling was based on the time of sampling and the procedure for each type of analysis was carried out following the Official Mexican Standard NOM-014-SSA1-1993 (SSA, 1994): "Sanitary procedures for sampling water for human use and consumption in public and private water supply systems". The water sampling process was considered simple and the measurements for each sample were carried out in triplicate.

The physicochemical analysis of water included the *in situ* measurement of temperature, total dissolved solids, electrical conductivity (EC), turbidity, and pH using a multiparametric potentiometer (HACH Conductivity Probe 51975-00), as well as the measurement of total hardness (mg/l $CaCO_3$), calcium hardness (mg/l $CaCO_3$), and anions (SO_4^{-2} and NO_3^-). Water samples were collected in polyethylene containers of 1 L capacity, previously washed with phosphate-free Extran and rinsed abundantly with deionized water, and subsequently, stored and transported at a temperature of 4 ° C for further analysis in the Environmental Sciences Research Laboratory located in the Autonomous University of San Luis Potosi (UASLP).

The measurement of total hardness in water samples was carried out using the volumetric method with EDTA following the recommendations of the Mexican Standard (NMX-AA-072-SCFI-2001). The sulfate ion in water samples was measured using a turbidimetric method (Method 4500-SO_4^{-2}; APHA, 1992), with some modifications developed by the American Society for Testing and Materials (ASTM D 516-90, Standard Test Method for Sulfate Ion in Water, 1995), whereas the measurement of nitrate ion was carried out using a UV spectroscopy method (Method 4500-NO_3; APHA, 1992). Total hardness (mg/l $CaCO_3$) and anions (SO_4^{-2} and NO_3^-) were measured using a UV-Vis spectrophotometer (AquaMate Plus Thermo Specific).

Water samples for microbiological analysis were collected in sterile bottles with a screw cap, with a capacity of 250 mL. The microbiological analysis in water samples was performed on the same water sampling day. The most probable number (MPN) method was used to estimate the total coliform bacteria in water samples, following the procedures indicated in the Official Mexican Standard NOM 112-SSA1-1994 (SSA, 1995), considering that the water is used for human consumption. In addition, the MPN of fecal coliforms (thermotolerant) was determined according to the Mexican Standard NMX-AA-042-SCFI-2015, using incubated and re-seeded tubes of brilliant green bile lactose broth at 44.5 ° C ± 0.2 ° C for 24 h ± 2 h; gas production was evaluated. The number of positive results from each set was compared with the standard chart to provide the presumptive coliform count per 100 mL water sample.

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Statistical analysis

The results were analyzed using the Statistics software (version 8.0 for Windows). One-way analysis of variance (ANOVA) was performed, and Fisher's least significant difference (LSD) procedure was used for the comparison of means with a statistically significant P-value ≤ 0.05.

Results

Table 1 shows the results of the physicochemical analyses of water from the 11 springs (M1-M11) adjacent to the Ciénega de Tamasopo natural wetland during the two sampling seasons (July and October 2017). In the first water sampling, the pH values (7.7-8.2) and temperature, ranging from 23 to 25 ° C, were within the maximum permissible limits proposed in the different regulatory agencies of water for human consumption (DOF, 1989; EPA, 2009; SSA, 2000).

Table 1. Physicochemical parameters of the springs surrounding the natural wetland Ciénega de Tamasopo in two samplings.

Spring	**pH**		**T (°C)**		**CE (µS/cm)**		**STD (mg/l)**		**Turbidity (NTU)**	
	Jul	**Oct**	**Jul**	**Oct**	**Jul**	**Oct**	**Jul**	**Oct**	**Jul**	**Oct**
M1 "Cabezas"	7.7	7.2	24	23	575.3	13.31	287.6	5.8	59	NA
M2 "Oscuranas 1"	8.1	7.5	24	23	573.8	13.16	286.9	5.8	0.17	NA
M3 "Oscuranas 2"	8.1	7.5	23	22	636.9	13.29	38.4	5.8	0.20	NA
M4 "El Cuajo"	8.0	7.3	24	23	1.68	13.49	839.5	5.9	124	NA
M5 "San Isidro"	7.9	7.3	24	23	1.73	13.80	863.5	6.1	0.96	NA
M6 "Cofradías"	8.1	7.3	24	23.5	1.71	13.70	852.5	6.0	0.06	NA
M7 "Presa Mocha"	8.0	7.3	24	23	1.84	13.82	919	6.1	0	NA
M8 "Agua de las Piedras"	7.7	NA	25	NA	777.2	NA	388.6	NA	0.76	NA
M9 "Plan de Juanchilote"	8.1	8.2	24	24	1.86	13.51	927.5	5.9	0.41	NA
M10 "Capuchinas"	8.0	7.4	25	22	595.0	13.26	297.5	5.8	0.37	NA
M11 "El 20"	8.2	8.0	25	24	1.66	13.39	829.5	5.9	NA	NA
Legislations										

Ecological Criteria for Water Quality, 1989	5.0-9.0	Natural conditions +2.5	NC	1 000	Natural conditions
NOM-127-SSA1-1994, mod 2000	6.5-8.5	NC	NC	1 000	5
EPA (2015)	5.0-9.0	NC	NC	250	NC
WHO (2018)	8.5	NC	NC	NC	NC
NA: Not available; NC: Not contemplated					

On the other hand, total dissolved solids (TDS) ranged from 38.4 to 927.5 ppm, and the sampling sites "El Cuajo" (M4), "San Isidro" (M5), "Cofradías" (M6), "Presa Mocha" (M7), and "El 20" (M11) showed the highest values of TDS. The sampling site "Agua de las Piedras" (M8) presented the highest value of electrical conductivity (777.2 μS/cm).

For the second water sampling (October 2017), the same *in situ* parameters were measured (Table 1), turbidity could not be measured because of an instrument failure. The pH ranged from 7.2 to 8.4 and a considerable decrease in TDS was observed in comparison to the first water sampling, with a range of 5.8 to 6.1 ppm (M5 "San Isidro" and M7 "Presa Mocha", respectively). The sampling site M2 "Oscuranas 1" presented the lowest value (13.16 μS/cm) of EC.

The water temperature was higher in the first water sampling, compared to the second sampling, in the springs M8 "Agua de las Piedras", M10 "Capuchinas" and M11 "El 20" (with 25 ° C). The EC was higher in the first water sampling (July 2017), compared to the second sampling (October 2017). The springs M3 "Oscuranas 2" (636.9 µS/cm), M8 "Agua de las piedras" (772.2 µS/cm), and M10 "Capuchinas" (595.0 µS/cm) showed the highest values of EC.

The highest value of turbidity was found during the first water sampling in the spring M4 "El Cuajo" (124 NTU) and M1 "Cabezas" (59 NTU). It is important to mention that the water from the M1 "Cabezas" spring is used mainly for domestic use since it is the pumping site for water distribution to the population of Ejido Cabezas; whereas in the spring M4 "El Cuajo," there is an electric water pump installed within nearby houses, which can cause the bottom sediment resuspension at the sampling point.

In addition, the determination of several important parameters, such as total hardness, hardness due to calcium, sulfates, and nitrates in the area was carried out to obtain complementary physicochemical analyses (Table 2).

Table 2. Determination of total hardness, calcium hardness ($CaCO_3$), Sulfates (SO_4^{-2}), and Nitrates (NO_3^-) of the springs surrounding the natural wetland Ciénega de Tamasopo in two samplings.

Spring	**Total hardness (mg/l $CaCO_3$)**		**Ca hardness (mg/l $CaCO_3$)**		**Sulfates (mg/l SO_4^{2-})**		**Nitrates (mg/l NO_3^-)**	
	Jul	Oct	Jul	Oct	Jul	Oct	Jul	Oct
M1 "Cabezas"	285.33±8.33	246.67±2.31	276.00±4.00	233.33±2.31	42.17±0.19	28.74±0.20	NA	1.01±0.001
M2 "Oscuranas 1"	306.67±6.11	229.33±8.33	201.33±2.31	166.67±2.31	85.35±0.48	37.16±0.56	NA	0.59±0.01
M3 "Oscuranas 2"	344.00±4.00	253.33±2.31	218.67±6.11	185.33±11.55	126.82±0.63	37.88±0.69	NA	0.48±0.01
M4 "El Cuajo"	749.33±11.31	388.00±8.00	418.67±11.31	206.67±6.11	302.30±4.00	218.21±1.31	NA	0.51±0.01
M5 "San Isidro"	944.00±2.83	628.00±4.00	672.00±11.31	421.33±4.62	278.23±0.65	277.39±1.12	NA	0.26±0.005

M6 "Cofradías"	937.33±8.49	361.33±6.11	622.67 ±2.83	280.00±4.00	279.00±0.43	235.32±1.94	NA	0.50±0.01
M7 "Presa Mocha"	1030.67±8.33	689.33±11.31	620.00 ±8.00	476.00±4.00	285.13±0.69	275.71±2.75	NA	0.21±0.004
M8 "Agua de las Piedras"	398.67±6.11	NA	333.33 ±8.49	NA	98.99±1.44	NA	NA	NA
M9 "Plan de Juanchilote"	302.67±4.62	456.00±8.00	253.33 ±2.31	340.00±4.00	285.65±1.09	230.94±0.20	NA	0.30±0.004
M10 "Capuchinas"	1009.33±8.49	258.67±2.31	628.00 ±19.80	242.67±2.31	64.73±0.001	34.40±0.66	NA	0.68±0.002
M11 "El 20"	846.67±4.62	321.33±6.11	698.67±2.31	224.00±8.00	271.54±1.68	133.01±3.19	NA	0.59±0.10
Legislations								
Ecological Criteria for Water Quality, 1989	NC		NC		500		5	
NOM-127-SSA1-1994, mod. 2000	500		NC		400		10	
EPA (2015)	500		NC		NC		NC	
WHO (2018)	NC		NC		NC		50	
NA: not available; NC: not contemplated								

The total water hardness values (mg/l $CaCO_3$) ranged from 285.33 ± 8.33 to 1030.67 ± 8.33 mg/l during the first water sampling (July 2017); considering this water is used for human consumption by the inhabitants of the neighboring communities. The Modified Official Mexican Standard NOM-127-SSA1-1994 (SSA, 2000) values were taken as reference, which establishes a maximum permissible limit for total water hardness up to 500 mg/l $CaCO_3$. The results of the first water sampling indicated that the total water hardness values (mg/l $CaCO_3$) in the springs M7 "Presa Mocha" with 1 030.67 ± 8.33 mg/l, followed by M10 "Capuchinas" with 1 009.33 ± 8.49 mg/l, M5 "San Isidro" with 944.00 ± 2.83 mg/l, M6 "Cofradías" with 937.33 ± 8.49 mg/l, M11 "El 20" with 846.67 ± 4.62 mg/l, and M4 "El Cuajo" with 749.33 ± 11.31 mg/l, are higher than the maximum permissible limits, whereas the rest of springs presented total water hardness values within the permissible limit.

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Regarding the determination of Ca hardness (mg/l $CaCO_3$), the values obtained during the first water sampling ranged from 201.33 ± 2.31 to 698.67 ± 2.31 mg/l and from 229.33 ± 8.33 mg/l to 689.33 ± 11.31 mg/l for the second sampling.

The anion analyses during the first water sampling showed the presence of sulfates in a range from 64.73 to 302.30 ± 4.0 mg/l. The springs M4 "El Cuajo" with 302.30 ± 4.00 mg/l, followed by M9 "Plan de Juanchilote" with 285.65 ± 1.09 mg/l, and M7 "Presa Mocha" with 285.13 ± 0.69 mg/l, showed the highest sulfate concentrations.

On the other hand, the analyses of sulfates and nitrates in the second water sampling showed the presence of both anions in concentrations ranging from 34.40 ± 0.66 -277.39 ± 1.12 mg L for sulfates and from 0.21-1.01 mg/l for nitrates. The highest sulfate concentration was found in springs M5 "San Isidro" (277.39 ± 1.12) and M7 "Presa Mocha 275.71 ± 2.75 mg/l, whereas the highest nitrate concentration was found in M1 "Cabezas" (1.01 mg/l) and M10 "Capuchinas" (0.68 mg/l).

Finally, Table 3 shows the microbiological analyses performed with the water samples from the 11 springs understudy only during the second sampling season (October 2017). Given the nature of the microbiological analysis, it was decided to carry out these studies only after the rainy season to determine the microbiological contribution caused by the mixture of rain and near-surface water, based on the World Health Organization (WHO, 2018) consideration that states: "rain can greatly increase the levels of microbial contamination in water sources and outbreaks of water-borne diseases are frequent after periods of rain".

Table 3. Microbiological analysis of the springs surrounding the natural wetland Ciénega de Cabezas (Second sampling).

Spring	**Total coliform bacteria (MPN/100 ml)**	**Fecal coliform bacteria (MPN 100/ml)**
M1 "Cabezas"	< 3	< 3
M2 "Oscuranas 1"	7	< 3
M3 "Oscuranas 2"	< 3	< 3
M4 "El Cuajo"	28	< 3
M5 "San Isidro"	< 3	< 3
M6 "Cofradías"	< 4	< 3
M7 "Presa Mocha"	< 5	< 3
M8 "Agua de las Piedras"	NA	NA
M9 "Plan de Juanchilote"	21	< 3
M10 "Capuchinas"	< 3	< 3
M11 "El 20"	< 3	< 3

Ecological Criteria for Water Quality, 1989	< 2	NC
NOM-127-SSA1-1994, mod. 2000	ND	ND
WHO (2018)	NC	ND
	95 % confidence level	
NA: not available; NC: not contemplated; ND: mot detectable.		

Table 3 shows the presence of total coliforms in the springs M2 "Oscuranas 1" (7 MPN/100 mL), M4 "El Cuajo" (28 MPN/100 mL), and M9 "Plan de Juanchilote" (21 MPN / 100 mL), whereas all springs showed the absence of fecal coliforms (<3 MPN/100 mL). However, the estimation of fecal coliforms in the spring M8 “Agua de las Piedras” could not be carried out due to persistent flooding, which did not allow the collection of water samples.

Discussion

In this study, the water quality of the springs (M1-M11) surrounding the natural wetland Ciénega de Tamasopo was determined given its importance for the enrichment of the water column. The physicochemical parameters were carried out considering that the spring water should not present disturbances due to anthropogenic contamination. However, given that the inhabitants of the communities surrounding the wetland consume water from the springs as drinking water, it was necessary to know the physicochemical parameters of this water to determine its suitability for human consumption, as well as the contribution that these springs have towards the wetland.

According to the current regulations established in the modified Official Mexican Standard NOM-127-SSA1-1994 (SSA, 2000), the permissible pH range for water quality for human use is 6.5-8.5, which can be interpreted as neutral alkaline, and all the sampling sites met this criterion in the two sampling seasons. These pH values, ranging from 6.25 to 7.67, are typical of continental systems in the springs that feed the Ciénega de Tamasopo wetland (Pérez-Castillo, 2017). Likewise, Puczko, Zieliński, and Jusik (2018) reported similar pH values (7.8-8.2) to those found in this study in the springs of the Knyszyn Forest Park, Poland, whereas Silva-García *et al*. (2016) reported pH values between 7 and 7.5 in the springs of the Duero River (Michoacan, Mexico), which correspond to alkaline water with pH values within the permissible limits.

The pH of water is an important parameter closely related to the biological productivity of ecological systems and it can be affected by anthropogenic activities, such as non-municipal water discharges, agricultural runoff, and atmospheric deposition of substances that form acids (Ramos-Herrera, Broca-Martinez, Laines-Canepa, & Carrera-Velueta, 2012). Other reasons for alkaline pH values in water may be the presence of HCO_3^- and CO_3^{-2} ions, which are formed during hydrothermal processes due to the presence of dissolved carbon dioxide (Roy, Kumar, Chowdhury, Singh, & Ray, 2018).

The leaching and dissolution of the aquifer material, as well as the mixing of saline sources, usually contribute to high EC values in water. A wide range of EC values in water samples is indicative of multiple ion sources from atmospheric, geogenic, and anthropogenic pollution (Leite *et al*., 2018; Thakur, Rishi, & Sharma, 2018).

Roy *et al*. (2018) conducted a study in the hot springs at Bakreswar, India, and obtained EC values between 410 to 783 µS/cm, which are attributed to the mineralization process and the weathering of the host rocks that promote the solubility of ionic compounds and can improve the total level of dissolved solids (TDS) in water. TDS is one of the parameters that allow evaluating the salinization of groundwater (Semarnat, 2018). In this context, water is considered unfit for human consumption if its TDS levels exceed 1 000 mg/l (DOF, 1989; SSA, 2000). According to this criterion, all the values obtained are within the maximum permissible limits in the two sampling seasons and therefore, can be considered suitable for human consumption.

The World Health Organization (WHO, 2018) does not establish a guide value for the content of total solids present in drinking water because it is not considered a parameter of concern for human health. However, the Environmental and Protection Agency in the United States

(EPA, 2015) recommends a limit value of 250 mg/l TDS in water used for human consumption. Thus, the sampling sites M4 "El Cuajo", M5 "San Isidro", M6 "Cofradías", M7 "Presa Mocha", M9 "Plan de Juanchilote", and M11 "El 20" are higher and exceed this limit. This may be explained since dissolved solids come from natural sources, such as leaves, sediment, rocks, and air, as well as sewage and agricultural runoff from fertilizers and pesticides. The TDS values found in this study are higher than those reported (130-490 mg/l) by Aksever, Davraz, and Bal (2016) in the springs of Başköy, Turkey, where the TDS values vary during circulation due to the contact with rocks, prolonged residence time of water, and recharge of springs from a high altitude. Rivera-Rodríguez, Beltrán-Hernández and Lucho-Constantino (2019) reported that the values found for EC (319-516 μS/cm) and TDS (139-258 mg/l) in the underground wells in Apan, Hidalgo (Mexico) indicate little mineralization due to a low residence time of the water.

For drinking water, a turbidity value of 5 NTU is generally acceptable (SSA, 2000), although this may vary according to the characteristics of the natural source. Furthermore, no adverse human health effects caused by a high turbidity in water have been reported (Chacón-Chumacero, Pinedo-Álvarez, & Rentería-Villalobos, 2016).

Hardness is a useful parameter to indicate the quality of water for domestic and industrial use. Ca and Mg dissolved in water are the two minerals that determine the hardness of water; which are the dominant ions of groundwater and influence carbonate dissolution (Aksever *et al.*, 2016; Singh, Kaur, & Katnoria, 2017). The high values of total hardness and calcium hardness observed in the sites M5 "San Isidro", M6

"Cofradías", and M7 "Presa Mocha" can be attributed to their location near a hill and the presence of calcareous soils. Therefore, during infiltration along with the flow, groundwater can dissolve $CaCO_3$ and $CaMg(CO_3)_2$ present in the rocks, and the calcium concentration of the groundwater can be increased Aksever *et al*., 2016)

The World Health Organization (WHO, 2018) does not propose a reference value based on human health effects for the hardness in drinking water. The taste threshold for the calcium ion is between 100 and 300 mg/l. In some cases, consumers tolerate a taste of water with hardness greater than 500 mg/l $CaCO_3$. Water with concentrations higher than 200 mg/l $CaCO_3$, depending on the interaction with other factors, such as pH and alkalinity, can cause scale formation in treatment facilities, distribution systems, pipes, and water storage tanks. Another consequence of water hardness is the excessive use of soap during laundry activities with the subsequent formation of insoluble soap residues. The acceptability by the population of the degree of water hardness varies greatly from one community to another, depending on the conditions of water use.

Regarding anions, during the first water sampling, only sulfates were detected, which were in the range of 64.73 to 302.30 ± 4.0 mg/l. In addition, the values obtained for sulfates showed a higher content of these anions during the first water sampling. It is important to mention that the springs M4 "El Cuajo", M7 "Presa Mocha", and M9 "Plan de Juanchilote" are surrounded by cane fields and during the first sampling season, the application of fertilizers and cane cutting takes place (harvest season). According to Almazán-Juárez *et al*. (2016), in the springs "Palo

Gordo" and "Agua Caliente", located in the Papagayo river basin, Guerrero (Mexico), the sulfate content was determined (62.68 and 45.58 mg/l SO_4^{-2}, respectively), which was considered within permissible levels, and lower to those compared with other aquatic mantles, such as Mediterranean areas where the sulfate contents are greater than 400 mg/l. The WHO (2018) has not yet defined reference values to establish the maximum permissible limits for sulfates in water according to the effects they might cause to human health. However, the presence of sulfates, at levels above 1 000 mg/l, in water for human consumption can generate a perceptible taste and rejection among users, which could cause a laxative effect in unaccustomed consumers. In general, deterioration in the taste of water is considered to be minimal when the concentration is less than 250 mg/l sulfates; in this sense, in the springs M4-M7 ("El Cuajo," San Isidro", "Cofradías" and "Presa Mocha"), M9 "Plan de Juanchilote" and M11 "El 20" there could be a slight alteration in the taste of water.

The presence of SO_4^{-2} in spring water is considered geogenic contamination produced by mineralization (Roy *et al*., 2018). In a work carried out by Pérez-Castillo (2017), sulfate values were reported between 3.1 and 229 mg/l (November 2010) and between 13.1 and 128.6 mg/l (May 2012) in the springs of the Ciénega de Tamasopo wetland. These values were attributed to the content of sulfates in spring water due to sulfur mineral dissolution reactions in geological deposits during upwelling and water flow, oxidation processes of iron sulfides (FeSx) mediated by nitrates in the water at the time of outcrop, and to the karstification process (dissolution of the calcareous substrate due to the infiltration of rainwater).

In rural areas, the use of nitrogenous fertilizers has led to a greater potential of groundwater contamination by excess nutrients, and nitrates are the most frequent pollutants introduced into groundwater systems (Aksever *et al*., 2016). The maximum allowable limit of NO_3^- for water for human consumption is 50 mg/l (WHO, 2018). However, nitrate concentration higher than 10 mg/l is indicative that the groundwater is being affected by anthropogenic factors, whereas, in natural conditions, nitrate concentration can be found less than 1 mg/l (Aksever, Davraz, & Karagüzel, 2015). Nitrate concentrations found in groundwater under aerobic conditions are a few milligrams per liter and depend on the type of soil and the geological situation (WHO, 2016). Therefore, it can be concluded that in 10 of the 11 study sites the concentration of nitrates is due to their natural condition, whereas the concentration of nitrates in M1 "Cabezas" (1.01 ± 0.001 mg/l), which was found within the permissible limits, may be due to its proximity to the population, and the presence of the pumping station in charge of the water distribution.

Regarding biological contamination, the presence of total coliforms and fecal coliforms is an indicator of anthropogenic activity, which represents a threat, implying an environmental impact and pressures to which springs may be subjected in terms of the presence of a source of contamination by wastewater, agricultural activities, population growth, and recreational activities, among others (Núñez, Fraile, & Lizarazu, 2009; Silva-García *et al*., 2016; Murphy, Prioleau, Borchardt, & Hynds, 2017). Fecal coliforms are one of the most important water quality parameters due to their use as a bacterial indicator of fecal contamination in natural waters, and therefore, their presence along pathogenic microorganisms can cause diseases (Leite *et al*., 2018).

According to our results, a value of 7 MPN/100 ml was reported for total coliforms in the M2 "Oscuranas 1", which may be due to the presence of a water electric pump in this site that distributes water to neighboring houses, and its location is a few meters away from the road that leads to the surrounding communities. In M4 "El Cuajo" is where the highest value of total coliforms was found with 28 MPN / 100 mL; this finding can be attributed to the presence of farm animals (pigs) and the opening of roads for the circulation of people into the spring; whereas in M9 "Plan de Juanchilote," 21 MPN / 100 mL were detected, which could be due to the presence of cane cutting workers who come to this site to bathe, and to the runoff of cattle feces that exist in one of the corrals near the spring.

Namihira-Santillán, Barrera-Escorcia, and Márquez-García (2002) attributed the values of total coliforms (150-6789 MPN/100 mL) and fecal coliforms (150-21 000 MPN/100 mL) of the external spring to Lake Huayamilpas, Mexico City (Mexico) as a result of the intermittent discharge of domestic wastewater and the surface runoff that occurs during the rainy months (June-September).

The springs M2 "Escuranas", M4 "Cuajo", and M9 "Plan de Juan Chilote" do not comply with the permissible limit of absent or undetectable levels for total coliforms established by the Modified Official Mexican Standard NOM-127-SSA1-1994 (SSA, 2000); therefore, a water purification process needs to be carried out in these springs before its consumption by humans. In addition, these springs do not meet the ecological criteria for water quality (CE-CCA-001/89) established for drinking water (<2 MPN of total coliform organisms/100 ml).

Although total coliforms were determined in three of the eleven springs, no fecal coliforms were detected in any of the springs. Therefore, the 11 springs comply with the Modified Official Mexican Standard NOM-127-SSA-1994 (SSA, 2000) that establishes the absence or not of detectable levels for fecal coliforms. However, there is not a tolerable lower limit for pathogenic microorganisms, therefore, the water intended for consumption, preparation of food and beverages, or personal hygiene must not contain any human pathogenic agent (Rivas-Robles, Espinosa-Niño, Hernández-Cruz, Guzmán-Monterrosa, & Pérez-Hernández, 2017). For this reason, it is important to frequently carry out this type of analysis and monitor other sources of water supply, especially in those springs where water, without any purification treatment is used for human consumption.

Untapped springs are exposed to the entry of pathogenic pollutants mainly due to their proximity to domestic farms or lands dedicated to livestock. However, those springs that did not present *in situ* contamination, such as the springs M1 "Cabezas" and M11 "El 20", which are located in the center of the town, may be vulnerable to contamination since their water is pumped into storage tanks in the open air. Of the springs studied, 50% are destined for human consumption, and the remaining springs flow into the natural wetland Cienega de Tamasopo. Therefore, it is even more important to know the quality of water and determine the possible environmental impacts that this ecosystem could suffer. The problems faced by the studied springs are varied due to anthropogenic and agricultural activities, therefore, it is necessary to undertake activities and projects for their protection and good use to avoid their deterioration.

Conclusions

The quality of the water from the springs that feed the Ciénega de Tamasopo natural wetland varies according to their location in the micro-basin and the anthropogenic activities associated with the communities surrounding the wetland. Some of the physicochemical and microbiological parameters determined in the springs exceeded the maximum permissible limits established in the regulations of water for human consumption. Therefore, it is advisable to establish a management plan to achieve the proper use and distribution of water of the 11 springs to their populations. In addition, it is necessary to implement constant monitoring to observe the variability of the physicochemical parameters during different times of the year and consider other physicochemical parameters to guarantee the quality of the water that reaches this natural wetland of Ramsar importance.

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References

Aksever, F., Davraz, A., & Bal, Y. (2016). Assessment of water quality for drinking and irrigation purposes: A case study of Başköy springs (Ağlasun/Burdur/Turkey). *Arabian Journal of Geosciences*, 9, 748.

Aksever, F., Davraz, A., & Karagüzel, R. (2015). Relations of hydrogeologic factors and temporal variations of nitrate contents in groundwater, Sandıklı Basin, Turkey. *Environmental Earth Sciences*, 73(5), 2179-2196.

Almazán-Juárez, M. A., Almazán-Juárez, A., Carreto-Pérez, B., Hernández-Castro, E., Damián-Nava, A., & Almazán-Núñez, R. (2016). Calidad y clasificación de usos del agua en la cuenca baja del río Papagayo, Guerrero, México. *Ecosistemas y Recursos Agropecuarios*, 3, 293-305.

APHA, American Public Health Association. (1992). *Standard methods for the examination of water and wastewater* (18th ed.). New York. USA: American Public Health Association.

Carbajal, J., Sánchez-De-Llanos, J., González, J., Del-Río, O., Gonzalvo, J., García, F., & Gutiérrez, D. (2015). Capítulo 2: Hidrología del Pánuco. En: *Fondo de Agua Metropolitano de Monterrey. México*. Recovered from http://famm.mx/wp-content/pdf/capitulo2-hidrologia-del-panuco.pdf

Chacón-Chumacero, K. O., Pinedo-Álvarez, C., & Rentería-Villalobos, M. (2016). Evaluación de elementos traza en agua de río y manantial del área minera de Ocampo, Chihuahua, México. *Revista Internacional de Contaminación Ambiental*, 32(4), 375-384. DOI:10.20937/rica.2016.32.04.01

Conanp, Comisión Nacional de Áreas Naturales Protegidas. (2020). ¿Por qué son importantes los humedales? Disponible en: http://www.conanp.gob.mx/conanp/dominios/ramsar/la_conanp_y_los_humedales.php

Norma Mexicana (2015). Norma Mexicana NMX-AA-042-SCFI-2015. Análisis de agua - Enumeración de organismos coliformes totales, organismos coliformes fecales (termotolerantes) y *Escherichia coli* - Método del número más probable en tubos múltiples. Diario oficial de la Federación, 11 de febrero de 2016, México. DF. 29p. Recuperado de https://www.gob.mx/cms/uploads/attachment/file/166147/nmx-aa-042-scfi-2015.pdf

Norma Mexicana (2001). Norma Mexicana NMX-AA-072-SCFI-2001. Análisis de agua-Determinación de dureza total en aguas naturales, residuales y residuales tratadas-método de prueba-(cancela a las NMX-AA-072-1981). Diario Oficial de la Federación. México. DF. 19p. Recuperado de https://www.gob.mx/cms/uploads/attachment/file/166788/NMX-AA-072-SCFI-2001.pdf

DOF, Diario Oficial de la Federación. (1989). Criterios ecológicos de calidad del agua. CEE-CCA-001/89. *Diario Oficial de la Federación*, 2 de diciembre, 26-36.

Derso, S., Beyene, A., & Getachew, M. (2015). Assessment of ecological quality of hot springs in the Eastern Amhara Region. *Environmental Systems Research*, 4, 19. Recovered from https://doi.org/10.1186/s40068-015-0044-z

EPA, Environmental Protection Agency. (2015). *National recommended water quality criteria*- Human health criteria table Recuperado de https://www.epa.gov/wqc/national-recommended-water-quality-criteria-human-health-criteria-table

Guo, M., Li, J., Sheng, C., Xu, J., & Wu, L. (2017). Una revisión de la teledetección de humedales. *Sensores*, 17(4), 777.

Instituto Nacional de Estadística, Geografía e Informática. (2010). Marco Geoestadístico de Ciénega de Cabezas, Tamasopo, San Luis Potosí. Ciudad de México, México.

Kaur, J., Walia, H., & Mabwoga, S. O. (2017). Water quality monitoring of an international wetland at Harike, Punjab and its impact on biological systems. *Applied Water Science*, 7, 1107-1115. DOI: 10.1007/s13201-015-0347-2

Kulinkina, A. V., Mohan, V. R., Francis, M. R., Kattula, D., Sarkar, R., & Plummer, J. D. (2016). Seasonality of water quality and diarrheal disease counts in urban and rural settings in South India. *Scientific Reports*, 6, 20521. DOI:10.1038/srep20521

Leite, N., Stolberg, J., Purin, S., Tavela, A., Safanelli, J., Marchini, H., Exterkoetter, R., & Johnson, M. (2018). Hydrochemistry of shallow groundwater and springs used for potable supply in Southern Brazil. *Environmental Earth Sciences*, 77. DOI:10.1007/s12665-018-7254-4

Lintern, A., Webb, J. A., Ryu, D., Liu, S., Bende-Mich, l. U., Waters, D., Leahy, P., Wilson, P., & Western, A. W. (2018). Key factors influencing differences in-stream water quality across space. *WIREs Water*, 5, (e1260), 31.

Moreno-Casasola, P. (ed.). 2016. *Servicios ecosistémicos de las selvas y bosques costeros de Veracruz*. Xalapa, México: : Instituto de Ecología A.C.-Organización Internacional de Maderas Tropicales-Comisión Nacional Forestal-Instituto Nacional de Ecología y Cambio Climático

Murphy, H. M., Prioleau, M. D, Borchardt, M. A., & Hynds, P. D. (2017) Epidemiological evidence of groundwater contribution to global enteric disease, 1948-2015. *Hydrogeology Journal*, 25(4), 981-1001.

Musalem, K., Jiménez, F., & McDonald, M. (2014). Application of a rapid assessment tool for integrated watershed management: A case study from La Plata River Basin in South America. *Aqua-LAC*, 5, 31-39.

Namihira-Santillán, P. E., Barrera-Escorcia, G., & Márquez-García, A. Z. (2002). Contaminación por bacterias fecales en el Lago Huayamilpas, México, D.F. *Hidrobiológica*, 12(2), 129-136.

Núñez, N., Fraile, I., & Lizarazu, J. (2009). Microorganismos patógenos del agua. Estudio de Molinao Erreka. *Meridies*, (13), 69-76.

Pérez-Castillo, F. V. (2017). *Dinámica de C, N, P y Fe en agua y sedimentos en el humedal natural Ciénega de Tamasopo, S.L.P.* (tesis de doctorado). Programas Multidisciplinarios de Posgrado en Ciencias Ambientales, Universidad Autónoma de San Luis Potosí.

Pérez-Castillo, F. V., Alfaro-De-la-Torre, M. C., Pérez-Rodríguez, R. Y., & Comín Sebastián, F. A. (2017). Tracing anthropogenic disturbances of a wetland through carbon and nitrogen isotope analyses in sediments. *Journal of Natural Resources and Development*, 07, 22-29.

Pérez-Castillo, F., Alfaro-De-la-Torre, M. C., Briones-Gallardo, R., & Medellín-Milán, P. (2015). Dinámica de nutrientes entre el agua y los sedimentos en el humedal natural Ciénega de Tamasopo, S. L. P. *1er Congreso Iberoamericano sobre sedimentos y ecología*, Querétaro, México.

Puczko, K., Zieliński, P., & Jusik, S. (2018). Vascular plant and bryophyte species richness in response to water quality in lowland spring niches with different anthropogenic impacts. *Environmental*

Monitoring and Assessment, 190, 338. Recovered from https://doi.org/10.1007/s10661-018-6703-6

Ramos-Herrera, S., Broca-Martinez, L. F., Laines-Canepa, J. R., & Carrera-Velueta, J. M. (2012). Tendencia de la calidad del agua en ríos de Tabasco, México. *Ingeniería*, 16, 207-217.

Ramsar. (2020). *La importancia de los humedales*. Recovered from https://www.ramsar.org/es/acerca-de/la-importancia-de-los-humedales

Ramsar Sites Information Service. (2008). *Ciénaga de Tamasopo*. Recovered from https://rsis.ramsar.org/ris/1814

Rivas-Robles, E., Espinosa-Niño, F., Hernández-Cruz, F., Guzmán-Monterrosa, H., & Pérez-Hernández, H. (2017). Caracterización fisicoquímica y bacteriológica del agua subterránea de Villa de Acapetahua (Chiapas, México). *Higiene y Sanidad Ambiental*, 17(3), 1541-1545.

Rivera-Rodríguez, D. A., Beltrán-Hernández, R. I., & Lucho-Constantino, C. A. (2019). Water quality indices for groundwater impacted by geogenic background and anthropogenic pollution: Case study in Hidalgo, Mexico. *International Journal of Environmental Science and Technology*, 16, 2201-2214. Recovered from https://doi.org/10.1007/s13762-018-1852-2

Roy, S., Kumar, B., Chowdhury, A., Singh, U. K., & Ray, S. (2018). Characterization of hydrogeochemical process and evaluation of water quality of seven geothermal springs, Bakreswar, India. *Arabian Journal of Geosciences*, 11, 314. https://doi.org/10.1007/s12517-018-3662-8

Semarnat, Secretaría de Medio Ambiente y Recursos Naturales. (2018) *Estadísticas del agua en México, edición 2018*. Ciudad de México, México: Secretaría de Medio Ambiente y Recursos Naturales, Comisión Nacional del Agua.

Silva-García, J. T., Ochoa-Estrada, S., Cruz-Cárdenas, G., Nava-Velázquez, J., & Villalpando-Barragán, F. (2016). Manantiales de la cuenca del río Duero Michoacán: operación, calidad y cantidad. *Revista Internacional de Contaminación Ambiental*, 32(1), 55-68.

Singh, N., Kaur, M., & Katnoria, J. (2017). Spatial and temporal heavy metal distribution and surface water characterization of Kanjli Wetland (a Ramsar site), India Using Different Indices. *Bulletin of Environmental Contamination and Toxicology*, 99. DOI:10.1007/s00128-017-2194-3

SSA, Secretaría de Salud. (22 de noviembre, 2000). Modificación a la norma NOM-127-SSA1-1994. Salud Ambiental. Agua para uso y consumo humano. Límites permisibles de calidad y tratamientos a que debe someterse el agua para su potabilización. *Diario Oficial de la Federación*. México, DF, México: Secretaría de Salud.

SSA, Secretaría de Salud. (19 de octubre, 1995). Norma Oficial Mexicana NOM-112-SSA1-1994. Bienes y servicios. Determinación de bacterias coliformes. Técnica del número más probable. *Diario Oficial de la Federación*. México, DF, México: Secretaría de Salud.

SSA, Secretaría de Salud. (12 de agosto, 1994). Norma Oficial Mexicana NOM-014-SSA1-1993. Procedimientos sanitarios para el muestreo de agua para uso y consumo humano en sistemas de abastecimiento de agua públicos y privados. *Diario Oficial de la Federación*. México, DF, México: Secretaría de Salud.

Suhani, I., Monika, Vaish, B., Singh, P., & Singh, R. P. (2020) Restoration, construction, and conservation of degrading wetlands: A step toward sustainable management practices. In: Upadhyay, A. K. *et al*. (eds.). *Restoration of wetland ecosystem: A trajectory towards a sustainable environment*. Recovered from https://doi.org/10.1007/978-981-13-7665-8_1

Thakur, N., Rishi, M., & Sharma, D.A. (2018). Quality of water resources in Kullu Valley in Himachal Himalayas, India: Perspective and prognosis. *Applied Water Science*, 8, 20. Recovered from https://doi.org/10.1007/s13201-018-0668-z

WHO, World Health Organization. (2018) *Guidelines for drinking-water quality: Fourth edition incorporating the first addendum*. Geneva, Switzerland: World Health Organization.

WHO, World Health Organization. (2016). *Nitrate and nitrite in drinking-water, background document for development of WHO guidelines for drinking-water quality*. Geneva, Switzerland: World Health Organization Press. Recuperado de https://www.who.int/water_sanitation_health/dwq/chemicals/nitrate-nitrite-background-jan17.pdf